EFFICIENT INDEX ASSIGNMENT BY IMPROVED BIT PROBABILITY ESTIMATION FOR PARALLEL PROCESSING OF DISTRIBUTED VIDEO CODING

Yoshihide Tonomura, Takayuki Nakachi and Tatsuya Fujii

NTT Network Innovation Laboratories
Nippon Telephone and Telegraph Corp. 239-0847 JAPAN

ABSTRACT

Distributed Video Coding (DVC) is attracting attention as a paradigm for video compression. One reason is that it transfers the high complexity computation to the decoder. However, the DVC decoder that uses channel coding based on a belief propagation algorithm has complexity exceeding that of the H.264/AVC encoder. This paper proposes a parallelized DVC scheme that treats each bitplane independently. Unfortunately, simple parallelization schemes suffer low compression efficiency because they can't use additional side information for the decoding of subsequent bitplanes. Therefore, we propose an effective estimation method that can calculate the bit probability as accurately as possible by index assignment. Simulations show that the proposed system can reduce the decode time by up to about 30-35[%] with only slight parallelization loss.

***Index Terms*—** Distributed source coding, LDPC codes, Parallel processing, Bitplane correlation, Gray code

1. INTRODUCTION

High-performance image compression has recently become extremely important since digital image data files continue to grow. One response was the international standard H.264/AVC. It is known that it can achieve compression rates 2 times higher than those possible with MPEG-2. A weakness of H.264/AVC is that the encoder needs a high level of computing power in order to support MC (Motion Compensation) and optimization of the macro block size. A new trend is the emergence of applications that permit low-complexity encoders. Examples of such applications include mobile camera phones and sensor network cameras. One approach to implementing these encoders is the Distributed Video Coding (DVC) system.

The DVC system is based on work by Slepian-Wolf and Wyner-Ziv. Wyner proposed using a linear code to enhance the DVC system. This structure transfers the high complexity computations to the decoder. One practice is intraframe video coding with interframe decoding[1]. In this system, encoders don't need to support MC because the decoder does. This means that the encoders can have low complexity. Another characteristic of the DVC system is robustness. The DVC system doesn't need to support MC at the encoders so it doesn't employ motion vectors, which means that the DVC system is drift-free.

For the above reasons, DVC is attracting researchers' attention as a new paradigm for video compression. However, a DVC decoder can be an order of magnitude more complex than a conventional video encoder such as H.264/AVC[2]. This is because the DVC decoder uses channel coding with a belief propagation algorithm. The use of this algorithm means that the DVC system suffers from excessive decoding times. In this paper, we propose a parallelized DVC system which treats each bitplane independently to reduce the decoding time. The simple application of parallelization causes low encoding efficiency since parallelized systems can't use additional side information for the decoding of subsequent bitplanes. There, we propose an information index assignment method to estimate bit probability as accurately as possible. Note that [3]-[4] proposed index assignment methods that provide more accurate probabilities for each bitplane. However, their methods compute only one probability for each bitplane. Our method, on the other hand, is focused on the parallelized DVC scheme and we investigate the relationship between bit probabilities for each pixel. Moreover, we propose a parity rate estimation method for the parallelized DVC scheme that uses the derived bit probability. Therefore, the proposed parallelized DVC system can perform rate control at the encoder side similar to [5].

2. BASIC DISTRIBUTED VIDEO CODING ARCHITECTURE

2.1. Pixel Domain Wyner-Ziv Codec

In this paper, we consider the DVC system architecture called the pixel domain Wyner-Ziv codec[1]. Fig1 illustrates a pixel domain Wyner-Ziv codec; note that LDPC codes replace Turbo codes for Slepian-Wold coding.

In the considered architecture, every odd-frame of the video sequence is mapped as a key frame$X_{2i\pm1}$ which is not compressed; these frames are assumed to be available to the decoder. Every even-frame of the video sequence is mapped as a Wyner-Ziv frameX_{2i}. These frames are compressed by a

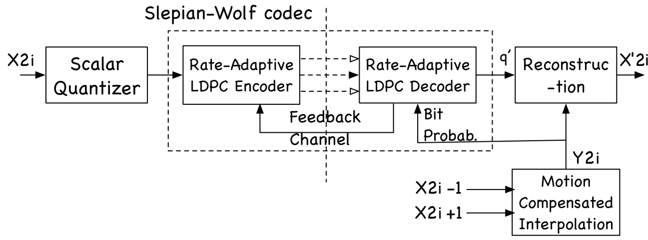

Fig. 1. Schematic diagram of pixel domain Wyner-Ziv codec

scalar quantizer and the Slepian-Wolf codec based on LDPC codes. First, Wyner-Ziv frames are quantized 2^M uniform quantization levels.These bitplanes are fed one by one into a rate-adaptive LDPC encoder. In the LDPC encoder, a sequence of input bits, $\mathcal{K}_l$, is mapped into the corresponding $\mathcal{C}_{l,i}$ syndrome bits. The encoder sends syndrome bits until the decoder can correctly decode the sequence.

At the decoder side, for each Wyner-Ziv frame, the decoder generates side informationY_{2i} from the key frames$X_{2i\pm1}$ by motion compensated interpolation. Next, we compute bit probabilities using the "$error''$ correlation model between the side informationY_{2i} and the original Wyner-Ziv frameX_{2i}. The residual between Wyner-Ziv frames and side information is modeled by a Laplacian distribution. Details of the bit probability computation method are described in the next subsection. The rate-adaptive LDPC decoder recovers the Wyner-Ziv frames using the bit probabilities and received syndrome bits.

Finally, the decoded symbol is reconstructed using the side information. The reconstruction operation for each pixel is given by

$$X'_{2i} = E[X_{2i}|q'_{2i}, Y_{2i}]. \quad (1)$$

2.2. Estimating Bit Probability for Non-Parallelized DVC

In the Wyner-Ziv codec, the decoder needs to estimate the correct "error" probabilities. The "error" probability$Pr[e_p]$ between Wyner-Ziv frames and side information is modeled by a Laplacian distribution and the probability that original Wyner-Ziv frame pixel$X_{2i}(n)$ is equal to x is evaluated as

$$Pr[X_{2i}(n) = x|Y_{2i}] = \frac{\alpha}{2}e^{-\alpha|x-Y_{2i}|}. \quad (2)$$

Next, we compute the probability for each bitplane. Assume that $X^l_{2i}(n)$ is the l-th bitplane value of $X_{2i}(n)$ and Z_l is the set of x values whose l-th bit equals 1. The probability of each bit $X^l_{2i}(n)$ is evaluated as

$$Pr[X^l_{2i}(n) = 1|X^{pre}_{2i}, Y_{2i}] = \frac{\sum\limits_{x\in Z_l} Pr[X_{2i}(n) = x|X^{pre}_{2i}, Y_{2i}]}{1 - \sum\limits_{x\notin\{0,1\ldots2^B-1\}} Pr[X_{2i}(n) = x|X^{pre}_{2i}, Y_{2i}]}, \quad (3)$$

where X^{pre}_{2n} denotes the previous (all those decoded) bitplanes of X^l, $\sum_{x\notin\{0,1\ldots2^B-1\}} Pr[X_{2i}(n) = x|Y_{2i}]$ is the probability that x exceeds image range and B is total bitplanes of image. Each Z_l is given by

$$\begin{cases} Z_0 & = \{2^{B-1}, ..., 2^B - 1\} \\ Z_1 & = \{2^{B-2}, ..., 2^{B-1} - 1\} \ \underline{or} \ \{3 \cdot 2^{B-2}, ..., 2^B - 1\} \\ \vdots & = \quad \vdots \end{cases} . \quad (4)$$

The range of Z_l is determined by X^{pre}_{2n}.

3. ESTIMATION METHOD FOR BIT PROBABILITIES IN PARALLELIZED SLEPIAN-WOLF CODEC

In this section, we describe an effective bit probability estimation method and a parity rate estimation method for the parallelized DVC system.

3.1. Bit Probability Estimation for Parallelized DVC

In the parallelized DVC scheme, the bitplanes are processed independently. Thus, we can not use the estimation method described in Section 2.2 because the decoded bitplanes X^{pre}_{2n} are not available at the decoder side. First, we extend the estimation method described above to suit the parallelized DVC, we call this the"simple method". Next, we propose an effective estimation method with index assignment called "Gray Code" for the parallelized DVC.

3.1.1. Simple Method

Simply, the probabilities are estimated, without using information about any other bitplane, as

$$Pr[X^l_{2i}(n) = 1|Y_{2i}] = \frac{\sum\limits_{x\in Z_l} Pr[X_{2i}(n) = x|Y_{2i}]}{1 - \sum\limits_{x\notin\{0,1\ldots2^B-1\}} Pr[X_{2i}(n) = x|Y_{2i}]}, \quad (5)$$

where each Z_l is given by

$$\begin{cases} Z_0 & = \{2^{B-1}, ..., 2^B - 1\} \\ Z_1 & = \{2^{B-2}, ..., 2^{B-1} - 1\} \ \underline{and} \ \{3 \cdot 2^{B-2}, ..., 2^B - 1\} \\ \vdots & = \quad \vdots \end{cases} . \quad (6)$$

3.1.2. Proposed Method

The *Simple method* can not provide accurate probability estimates because, from Eq(6), given the case of $X^1_{2i}(n) \neq Y^1_{2i}(n)$, the second bitplane's estimated probability is very far from its true value. Now, we consider the example of 3-bit ($B = 3$) in Fig.3 (a). When the parameters are given as

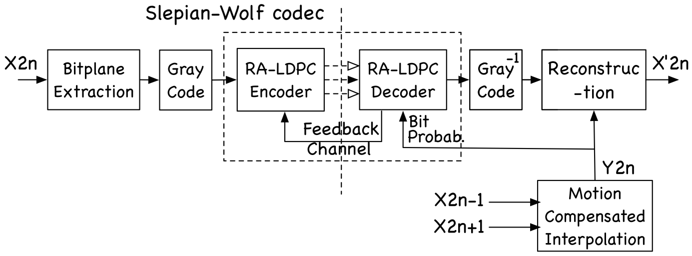

Fig. 2. Schematic diagram of proposed Wyner-Ziv codec

$X_{2i}(n) = 3$,$Y_{2i}(n) = 4$ and $Pr[e_p]$ as shown in Table1. Eq(5)(6) yields $Pr[X^1_{2i}(n) = 1|Y_{2i}] = 0.70$, while Eq(5)(6) yields $Pr[X^2_{2i}(n) = 1|Y_{2i}] = 0.45$.

The LDPC code uses syndrome bit and log-likelihood ratio(llr). The llr is defined by

$$L^l(n) = \log \frac{Pr[X^l_{2i}(n) = 1|Y_{2i}]}{1 - Pr[X^l_{2i}(n) = 1|Y_{2i}]}. \quad (7)$$

From Eq(7), if $0 < L^l(n)$, the LDPC decoder assumes that $X^l_{2i}(n) = 1$. In the above example, Eq(7) yields $L^1(n) = 0.84$, while Eq(7) yields $L^2(n) = -0.2$. Therefore, when using Eq(5)(6), the LDPC decoder is misled into thinking that $X^1(n) = 1$ and $X^2(n) = 0$, and a lot of parity bits are required to correct these "errors".

For the above reasons, the simple method suffers low encoding efficiency. To solve this problem, we introduce the index assignment method called the "Gray Code"[6]. Consider the binary code in Fig.3 (a); the first bitplane's binary change point (between 0 and 1) lies between 3-4, while the second bitplane's binary change point (between 0 and 1) lies between 1-2, 3-4, and 5-6. That is, the binary code allows two sequential bitplanes to share at least one change point. The Gray code, on the other hand, ensures that sequential bitplanes share no change point(Fig.3(b)). As a result, the $Proposed\ method$ using gray code can provide accurate probability estimates even when $X^{pre}_{2i}(n) \neq Y^{pre}_{2i}(n)$. This is why the Gray code helps the parallelized DVC scheme.

We extend this discussion to consider a more general practical case, we compute each bitplane's probability as follows. The equation is derived in the same way as Eq (5), but each Z_l is given by

$$\begin{cases} Z_0 & = \{2^{B-1}, ..., 2^B - 1\} \\ Z_1 & = \{2^{B-2}, ..., 3 \cdot 2^{B-2} - 1\} \\ Z_2 & = \{2^{B-3}, ..., 3 \cdot 2^{B-3} - 1\} ... \\ & \quad \underline{and}\ \{5 \cdot 2^{B-3}, ..., 7 \cdot 2^{B-3} - 1\} \\ \vdots & = \quad \vdots \end{cases} . \quad (8)$$

For the above example, Eq(5)(8) yields $Pr[X^2_{2i}(n) = 1|Y_{2i}] = 0.85$ and $L^1(n) = 1.7$. This shows that the estimation method can calculate bit probability as accurately as possible. The proposed DVC scheme is illustrated in Fig2.

Table 1. Example of probabilities for 3-bit

e_p	-4	-3	-2	-1	0	1	2	3
$Pr[e_p]$	0	0	0.1	0.2	0.35	0.2	0.1	0.05

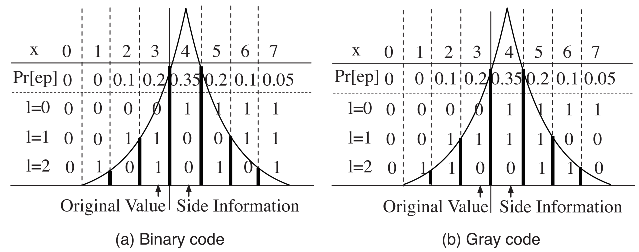

Fig. 3. Example of Binary code and Gray code for 3-bit

3.2. Parity Rate Estimation for Parallelized DVC

To avoid feedback channel complexity, we use an encoder rate control(ERC) framework similar to [5]. In the parallelized DVC system, parity rate estimation is easier to perform than is true with the non-parallelized DVC system. The probability of mismatch between $X^l(n)$ and $Y^l(n)$ is computed from

$$\begin{aligned} P^l_e = & \frac{1}{N} \sum_n Pr[X^l(n) = 1|Y^l(n) = 0, Y_{2i}] \\ & + \frac{1}{N} \sum_n Pr[X^l(n) = 0|Y^l(n) = 1, Y_{2i}]. \end{aligned} \quad (9)$$

We estimate the l-th bitplane's parity rate is as follows

$$\hat{R}^l \approx P^l_e \times \log_2 \left[\frac{1}{P^l_e}\right] + [1 - P^l_e] \times \log_2 \left[\frac{1}{1 - P^l_e}\right]. \quad (10)$$

4. SIMULATION RESULTS

In this section, we evaluate the compression performance of the proposed parallelized DVC scheme. The results for 30 frames of the *Foreman* and the *News* Gray-scale QCIF sequences are shown in Fig.4. In this simulation, the Wyner-Ziv frames were divided into four tiles; each tile was compressed using the regular LDPC($k = 6336$) codec and optimal α was computed using the original version of the Wyner-Ziv frame. The two sequences had average α values of 0.4 and 0.8, respectively. Fig.4 shows that the proposed method has compression performance equaling that of the non-parallelized DVC scheme and about 3 [dB] better compression than the "simple method" at the same bitrate of 1.5[bpp]. In addition, our proposed method works well if α is large.

Next, we measured the decoding time using the *Foreman* sequence for PSNR values of 38[dB] and 42[dB] with each method on a Mac Pro(2×3 GHz Dual Core Intel Xeon). The result, shown in Table2, confirms that the parallelized DVC scheme reduces the decoding times by up to about 30-35[%].

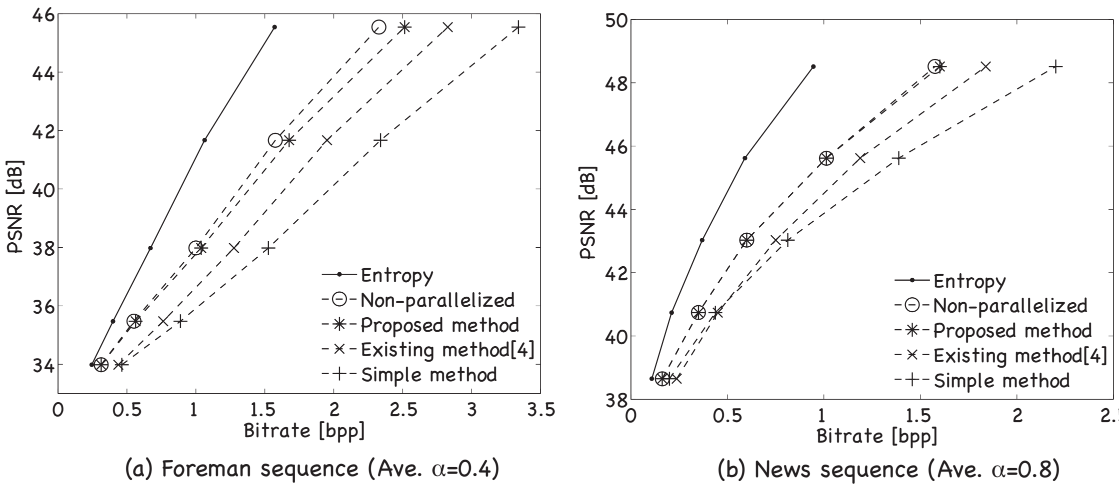

Fig. 4. Compression performance of Wyner-Ziv coding

Table 2. Average decoding time per frame

Foreman sequence (PSNR = 38[dB])	
Existing Method (non-parallelized)	1.57[sec]
Simple Method (parallelized)	0.63[sec]
Existing Method[4] (parallelized)	0.45[sec]
Proposed method (parallelized)	0.46[sec]
Foreman sequence (PSNR = 42[dB])	
Existing Method (non-parallelized)	2.08[sec]
Simple Method (parallelized)	0.70[sec]
Existing Method[4] (parallelized)	0.68[sec]
Proposed method (parallelized)	0.70 [sec]

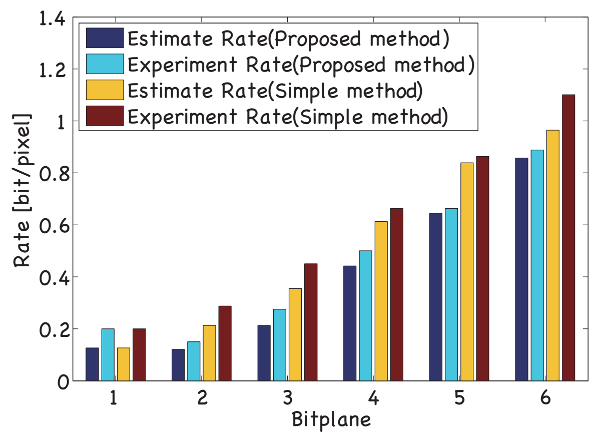

Fig. 5. Evaluation of proposed parity rate estimation method (Foreman sequence)

Finally, we evaluated the proposed estimation method using the *Foreman* and the result shown in Fig.5. In Fig.5, difference between the estimated rate and the experimental rate are small. The maximum difference between them was only 0.13[bpp]. It is possible to reduce feedback complexity.

5. SUMMARY

In this paper, we proposed a parallelized DVC system.To realize this system, we proposed an accurate estimation method for each bit probability with an index assignment method called "Gray Codes". Simulation results show that the proposed system can reduce the decode time by up to about 30-35[%] with only slight parallelization loss. Moreover, we proposed a parity rate estimation method for the parallelized DVC system. Using this estimation method, the parallelized DVC system can perform rate control at the encoder side with pretty accurate bitrates.

6. REFERENCES

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